it may be desirable to have a tool made with a small compressive residual stress to urge small cracks in the tool to close. Currently, there is no way to design a tool with that type of compressive stress retained therein regardless of whether it is spray formed or made another way; it is simply luck if it occurs. The one dimensional simulation provides a sufficient fidelity of the control process to actually design parts in which there is a compressive residual stress on the working surface of a tool, such as a stamp. That means the tool lasts much longer, because the cracks are under a compressive load that minimizes a tendency of the cracks to cycle open and shut and eventually rip apart during use of the tool.

[0104] In summary, the characterizations and anecdotal data contained herein demonstrate the utility and success of the presently disclosed inventions' advantageous integration of the time, temperature, and transformation dependent stress relief techniques into a thermal spray process. The spray form process can be advantageously used to create steel articles with complex surface topology by spraying molten steel onto a ceramic substrate representing the required surface structure. Such steel billets can be utilized as tools, particularly stamping tools, in the automotive, as well as other industries requiring metal-faced tools. Advantageously, these tools can be rapidly created using the spray form process. As a refinement of the spraying process, temperature control in the form of heat input to the spray environment can be advantageously employed before, during and after the actual spray deposit of the moltenized metal. From a control aspect, the one dimensional model that has been described can be utilized for predictive analysis, as well as feed-forward control of the spray process.

[0105] Various preferred embodiments of the invention have been described in fulfillment of the various objects of the invention. It should be recognized that these embodiments are merely illustrative of the principles of the invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in the art without departing from the spirit and scope of the present invention.

Claims

[c1]

1. A method for implementing post-heat treatment during spray forming to achieve stress control in the manufacture of a spray formed metallic tool, comprising:applying a metallic spray-forming material at a preselected application temperature upon a mold substrate heated to a preselected substrate temperature disposed within a spray forming cell environment heated to a preselected spray forming cell environment temperature in the manufacture of a spray-formed tool;

causing preselected substantially homogenous metallic phase transformations from an austenite phase of the spray forming material to a substantially homogenous distribution of commingled metallic phases consisting of a predetermined proportion of at least one of a bainite phase, a pearlite-ferrite phase, and a martinsite phase of the spray forming material; and

wherein the substantially homogenous metallic phase transformations are caused at least in part via manipulation of at least one of the substrate temperature and the spray forming cell environment temperature.

[c2]

2. The method of claim 1, wherein causing the metallic phase transformations further comprises causing substantially homogenous volumetric changes in the spray forming material associated at least in part with the metallic phase transformations of the spray forming material.

[c3]

3. The method of claim 2, wherein causing the metallic phase transformations further comprises causing the metallic phase transformations to the substantially homogenous distribution of commingled metallic phases consisting of the predetermined proportion of at least one of the bainite phase, the pearlite-ferrite phase, and the martinsite phase and a predetermined proportion of the austenite phase of the spray forming material.

[c4]

4. The method of claim 1, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining at least one of the mold substrate and the spray forming cell environment at the preselected temperature that is at least as great as the preselected application temperature for a predetermined time interval and thereafter decreasing the temperature of the at least one of the mold substrate and the spray forming cell environment to a second preselected temperature that is less than the preselected application temperature.

[c5]

5. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises decreasing the temperature of the at least one of the mold substrate and the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and greater than a martinsite start temperature of the spray forming material.

[c6]

6. The method of claim 5, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining the at least one of the mold substrate and the spray forming cell environment at the second preselected temperature for a second predetermined time interval and thereafter decreasing the temperature of the at least one of the mold substrate and the spray forming cell environment to a third preselected temperature that is less than the preselected application temperature and less than the martinsite start temperature of the spray forming material.

[c7]

7. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises decreasing the temperature of the at least one of the mold substrate and the spray forming cell environment to a second preselected temperature that is less than the preselected application temperature and less than a martinsite start temperature of the spray forming material.

[c8]

8. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining both of the mold substrate and the spray forming cell environment at the preselected temperature that is at least as great as the preselected application temperature for the predetermined time interval and thereafter decreasing the temperature of both of the mold substrate and the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and greater than a martinsite start temperature of the spray forming material.

[c9]

9. The method of claim 8, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining both the mold substrate and the spray forming cell environment at the second preselected temperature for a second predetermined time interval and thereafter decreasing the temperature of both the mold substrate and the spray forming cell environment to a third preselected temperature that is less than the preselected application temperature and less than the martinsite start temperature of the spray forming material.

[c10]

10. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining both the mold substrate and the spray forming cell environment at the

preselected temperature that is at least as great as the preselected application temperature for the predetermined time interval and thereafter decreasing the temperature of both the mold substrate and the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and less than a martinsite start temperature of the spray forming material.

[c11]

11. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining the spray forming cell environment at the preselected temperature that is at least as great as the preselected application temperature for the predetermined time interval and thereafter decreasing the temperature of the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and greater than a martinsite start temperature of the spray forming material.

[c12]

12. The method of claim 11, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining the spray forming cell environment at the second preselected temperature for a second predetermined time interval and thereafter decreasing the temperature of the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and less than the martinsite start temperature of the spray forming material.

[c13]

13. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining the spray forming cell environment at the preselected temperature that is at least as great as the preselected application temperature for the predetermined time interval and thereafter decreasing the temperature of the spray forming cell environment to the second preselected temperature that is less than the preselected application temperature and less than a martinsite start temperature of the spray forming material.

[c14]

14. The method of claim 4, wherein the manipulation of at least one of the substrate temperature and the spray forming cell environment temperature further comprises maintaining the mold substrate at the preselected temperature that is at least as great as the preselected application temperature for the predetermined time interval and thereafter decreasing the temperature of the mold substrate to the second preselected